

CLAIMS

- 1 1. A computer system configured by machine instructions to operate as a virtual ma-
2 chine that responds to virtual-machine code, which virtual-machine code defines a muta-
3 tor that dynamically allocates memory in a heap to data objects and writes in reference
4 fields references to such objects, by:
- 5 A) executing a garbage collector that:
- 6 i) treats the heap as divided into regions;
- 7 ii) determines whether objects to which memory in the heap has been
8 dynamically allocated satisfy a popular-object criterion;
- 9 iii) places into certain, popular-object regions the objects that it
10 thereby determines satisfy such a criterion and excludes from such
11 regions objects that it thereby determines do not satisfy such a cri-
12 terion;
- 13 iv) maintains for each of a plurality of the regions other than the popu-
14 lar-object regions a respective remembered set that lists where ref-
15 erences in other regions to that region have been written; and
- 16 v) updates the remembered sets in response to reference-written noti-
17 fications from the mutator; and
- 18 B) so executing the mutator that, in at least some situations in which the mu-
19 tator writes a reference into a reference field in the heap, the mutator:
- 20 i) makes a normal-region determination of whether the reference re-
21 fers to an object that is not located in a popular-object region;
- 22 ii) makes a reference-written notification to the garbage collector if
23 the normal-region determination's result is that the reference refers
24 to an object that is not located in a popular-object region; and
- 25 iii) otherwise refrains from making such a notification.

1 2 A computer system as defined in claim 1 wherein:
2 A) the garbage collector treats the heap as additionally divided into cards;
3 B) the mutator maintains at least one remembered-set log; and
4 C) the reference-written notification includes placing into one such remem-
5 bered-set log an identifier of the card in which the reference's containing
6 object starts.

1 3 A computer system as defined in claim 1 wherein the garbage collector makes a
2 popular-region determination of whether regions that are not popular-object regions sat-
3 isfy a popular-region criterion and, when such a region is thereby determined to satisfy
4 the popular-region criterion:

5 A) counts references to objects in the region with which that remembered set
6 is associated; and
7 B) places into popular-object regions objects to which the numbers of refer-
8 ences are thereby found to exceed a popular-object threshold.

1 4. A computer system as defined in claim 3 wherein the garbage collector makes the
2 popular-region determination as part of maintaining the remembered sets.

1 5. A computer system as defined in claim 1 wherein the normal-region determina-
2 tion's result is negative if the reference satisfies a popular-object-region criterion.

1 6. A computer system as defined in claim 5 wherein the popular-object-region de-
2 termination's result is negative if the reference is a distinguished, NULL value that indi-
3 cates that the reference refers to no object.

1 7. A computer system as defined in claim 6 wherein the popular-object-region crite-
2 rion is that the reference's value be less than a popular-object-region threshold.

1 8. A computer system as defined in claim 7 wherein the NULL value is less than the
2 popular-object-region threshold.

1 9. A storage medium containing instructions readable by a computer system to con-
2 figure the computer system to operate as a virtual machine that responds to virtual-
3 machine code, which virtual-machine code defines a mutator that dynamically allocates
4 memory in a heap to data objects and writes in reference fields references to such objects,
5 by:

- 6 A) executing a garbage collector that:
- 7 i) treats the heap as divided into regions;
- 8 ii) determines whether objects to which memory in the heap has been
9 dynamically allocated satisfy a popular-object criterion;
- 10 iii) places into certain, popular-object regions the objects that it
11 thereby determines satisfy such a criterion and excludes from such
12 regions objects that it thereby determines do not satisfy such a cri-
13 terion;
- 14 iv) maintains for each of a plurality of the regions other than the popu-
15 lar-object regions a respective remembered set that lists where ref-
16 erences in other regions to that region have been written; and
- 17 v) updates the remembered sets in response to reference-written noti-
18 fications from the mutator; and
- 19 B) so executing the mutator that, in at least some situations in which the mu-
20 tator writes a reference into a reference field in the heap, the mutator:
- 21 i) makes a normal-region determination of whether the reference re-
22 fers to an object that is not located in a popular-object region;
- 23 ii) makes a reference-written notification to the garbage collector if
24 the normal-region determination's result is that the reference refers
25 to an object that is not located in a popular-object region; and
- 26 iii) otherwise refrains from making such a notification.

1 10 A storage medium as defined in claim 9 wherein:

- 2 A) the garbage collector treats the heap as additionally divided into cards;
3 B) the mutator maintains at least one remembered-set log; and
4 C) the reference-written notification includes placing into one such remem-
5 bered-set log an identifier of the card in which the reference's containing
6 object starts.

1 11 A storage medium as defined in claim 9 wherein the garbage collector makes a
2 popular-region determination of whether regions that are not popular-object regions sat-
3 isfy a popular-region criterion and, when such a region is thereby determined to satisfy
4 the popular-region criterion:

- 5 A) counts references to objects in the region with which that remembered set
6 is associated; and
7 B) places into popular-object regions objects to which the numbers of refer-
8 ences are thereby found to exceed a popular-object threshold.

1 12. A storage medium as defined in claim 11 wherein the garbage collector makes the
2 popular-region determination as part of maintaining the remembered sets.

1 13. A storage medium as defined in claim 9 wherein the normal-region determina-
2 tion's result is negative if the reference satisfies a popular-object-region criterion.

1 14. A storage medium as defined in claim 13 wherein the popular-object-region de-
2 termination's result is negative if the reference is a distinguished, NULL value that indi-
3 cates that the reference refers to no object.

1 15. A storage medium as defined in claim 14 wherein the popular-object-region crite-
2 rion is that the reference's value be less than a popular-object-region threshold.

1 16. A storage medium as defined in claim 15 wherein the NULL value is less than the
2 popular-object-region threshold.

1 17. An electromagnetic signal representing instructions readable by a computer sys-
2 tem to configure the computer system to operate as a virtual machine that responds to vir-
3 tual-machine code, which virtual-machine code defines a mutator that dynamically allo-
4 cates memory in a heap to data objects and writes in reference fields references to such
5 objects, by:

- 6 A) executing a garbage collector that:
- 7 i) treats the heap as divided into regions;
- 8 ii) determines whether objects to which memory in the heap has been
9 dynamically allocated satisfy a popular-object criterion;
- 10 iii) places into certain, popular-object regions the objects that it
11 thereby determines satisfy such a criterion and excludes from such
12 regions objects that it thereby determines do not satisfy such a cri-
13 terion;
- 14 iv) maintains for each of a plurality of the regions other than the popu-
15 lar-object regions a respective remembered set that lists where ref-
16 erences in other regions to that region have been written; and
- 17 v) updates the remembered sets in response to reference-written noti-
18 fications from the mutator; and
- 19 B) so executing the mutator that, in at least some situations in which the mu-
20 tator writes a reference into a reference field in the heap, the mutator:
- 21 i) makes a normal-region determination of whether the reference re-
22 fers to an object that is not located in a popular-object region;
- 23 ii) makes a reference-written notification to the garbage collector if
24 the normal-region determination's result is that the reference refers
25 to an object that is not located in a popular-object region; and

26 iii) otherwise refrains from making such a notification.

1 18 An electromagnetic signal as defined in claim 17 wherein:

- 2 A) the garbage collector treats the heap as additionally divided into cards;
3 B) the mutator maintains at least one remembered-set log; and
4 C) the reference-written notification includes placing into one such remem-
5 bered-set log an identifier of the card in which the reference's containing
6 object starts.

1 19 An electromagnetic signal as defined in claim 17 wherein the garbage collector
2 makes a popular-region determination of whether regions that are not popular-object re-
3 gions satisfy a popular-region criterion and, when such a region is thereby determined to
4 satisfy the popular-region criterion:

- 5 A) counts references to objects in the region with which that remembered set
6 is associated; and
7 B) places into popular-object regions objects to which the numbers of refer-
8 ences are thereby found to exceed a popular-object threshold.

1 20. An electromagnetic signal as defined in claim 19 wherein the garbage collector
2 makes the popular-region determination as part of maintaining the remembered sets.

1 21. An electromagnetic signal as defined in claim 17 wherein the normal-region de-
2 termination's result is negative if the reference satisfies a popular-object-region criterion.

1 22. An electromagnetic signal as defined in claim 21 wherein the popular-object-
2 region determination's result is negative if the reference is a distinguished, NULL value
3 that indicates that the reference refers to no object.

1 23. An electromagnetic signal as defined in claim 22 wherein the popular-object-
2 region criterion is that the reference's value be less than a popular-object-region thresh-
3 old.

1 24. An electromagnetic signal as defined in claim 23 wherein the NULL value is less
2 than the popular-object-region threshold.

1 25. A method of employing a computer system as a virtual machine that responds to
2 virtual-machine code, which virtual-machine code defines a mutator that dynamically
3 allocates memory in a heap to data objects and writes in reference fields references to
4 such objects, by causing the computer system to:

- 5 A) executing a garbage collector that:
 - 6 i) treats the heap as divided into regions;
 - 7 ii) determines whether objects to which memory in the heap has been
8 dynamically allocated satisfy a popular-object criterion;
 - 9 iii) places into certain, popular-object regions the objects that it
10 thereby determines satisfy such a criterion and excludes from such
11 regions objects that it thereby determines do not satisfy such a cri-
12 terion;
 - 13 iv) maintains for each of a plurality of the regions other than the popu-
14 lar-object regions a respective remembered set that lists where ref-
15 erences in other regions to that region have been written; and
 - 16 v) updates the remembered sets in response to reference-written noti-
17 fications from the mutator; and
- 18 B) so execute the mutator that, in at least some situations in which the muta-
19 tor writes a reference into a reference field in the heap, the mutator:
 - 20 i) makes a normal-region determination of whether the reference re-
21 fers to an object that is not located in a popular-object region;

- 22 ii) makes a reference-written notification to the garbage collector if
23 the normal-region determination's result is that the reference refers
24 to an object that is not located in a popular-object region; and
25 iii) otherwise refrains from making such a notification.

1 26 A method as defined in claim 25 wherein:

- 2 A) the garbage collector treats the heap as additionally divided into cards;
3 B) the mutator maintains at least one remembered-set log; and
4 C) the reference-written notification includes placing into one such remem-
5 bered-set log an identifier of the card in which the reference's containing
6 object starts.

1 27 A method as defined in claim 25 wherein the garbage collector makes a popular-
2 region determination of whether regions that are not popular-object regions satisfy a
3 popular-region criterion and, when such a region is thereby determined to satisfy the
4 popular-region criterion:

- 5 A) counts references to objects in the region with which that remembered set
6 is associated; and
7 B) places into popular-object regions objects to which the numbers of refer-
8 ences are thereby found to exceed a popular-object threshold.

1 28. A method as defined in claim 27 wherein the garbage collector makes the popu-
2 lar-region determination as part of maintaining the remembered sets.

1 29. A method as defined in claim 25 wherein the normal-region determination's result
2 is negative if the reference satisfies a popular-object-region criterion.

1 30. A method as defined in claim 29 wherein the popular-object-region determina-
2 tion's result is negative if the reference is a distinguished, NULL value that indicates that
3 the reference refers to no object.

1 31. A method as defined in claim 30 wherein the popular-object-region criterion is
2 that the reference's value be less than a popular-object-region threshold.

1 32. A method as defined in claim 31 wherein the NULL value is less than the popu-
2 lar-object-region threshold.

1 33. A virtual machine that responds to virtual-machine code, which virtual-machine
2 code defines a mutator that dynamically allocates memory in a heap to data objects and
3 writes in reference fields references to such objects, the virtual machine including:

- 4 A) a garbage collector that treats the heap as divided into regions and com-
5 prises:
6 i) means for determining whether objects to which memory in the
7 heap has been dynamically allocated satisfy a popular-object crite-
8 rion;
9 ii) means for placing into certain, popular-object regions the objects
10 that it thereby determines satisfy such a criterion and excludes
11 from such regions objects that it thereby determines do not satisfy
12 such a criterion;
13 iii) means for maintaining for each of a plurality of the regions other
14 than the popular-object regions a respective remembered set that
15 lists where references in other regions to that region have been
16 written; and
17 iv) means for updating the remembered sets in response to reference-
18 written notifications from the mutator; and

- 19 B) means for so executing the mutator that, in at least some situations in
20 which the mutator writes a reference into a reference field in the heap, the
21 mutator:
- 22 i) makes a normal-region determination of whether the reference re-
 - 23 fers to an object that is not located in a popular-object region;
 - 24 ii) makes a reference-written notification to the garbage collector if
 - 25 the normal-region determination's result is that the reference refers
 - 26 to an object that is not located in a popular-object region; and
 - 27 iii) otherwise refrains from making such a notification.